

Phenomenological approach to profile impact of scientific research: Citation Mining*

J. A. del Rio,
Centro de Investigacion en Energia,
Universidad Nacional Autonoma de Mexico,
A.P. 34 Temixco, Mor. Mexico

R. N. Kostoff,
Office of Naval Research Arlington, VA, USA

E. O. Garcia, A. M. Ramirez
Centro de Investigacion en Energia,
Universidad Nacional Autonoma de Mexico,
A.P.34 Temixco, Mor. Mexico

and J. A. Humenik
NOESIS, Inc. Rockville, MD, USA

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Abstract

In this paper we present a phenomenological approach to describe a complex system: scientific research impact through Citation Mining. The novel concept of Citation Mining, a combination of citation bibliometrics and text mining, is used for the phenomenological description. Citation Mining starts with a group of core papers whose impact is to be examined, retrieves the papers that cite these core papers, and then analyzes the bibliometrics characteristics of the citing papers as well as their linguistic and thematic characteristics. The Science Citation Index is used as the source database for the core and citing papers, since its citation-based structure enables the capability to perform citation studies easily. This paper presents illustrative examples in photovoltaics (applied research) and sandpile dynamics (basic research) to show the types of output products possible. Bibliometric profiling is performed over a number of the citing papers' record fields to offer different perspectives on the citing (user) community. Text mining is performed on the aggregate citing papers,

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to identify aggregate citing community themes, and to identify extra-discipline and applications themes. The photovoltaics applied research papers had on the order of hundreds of citations in aggregate. All of the citing papers ranged from applied research to applications, and their main themes were fully aligned with those of the aggregate cited papers. This seems to be the typical case with applied research. The sandpile dynamics basic research papers had hundreds of citations in aggregate. Most of the citing papers were also basic research whose main themes were aligned with those of the cited paper. This is typically the case with basic research. However, about twenty percent of the citing papers were research or development in other disciplines, or development within the same discipline. In addition, there was a four year lag time between publication and citation by the development papers.

1 INTRODUCTION

Most scientists publish their findings to disseminate their research results widely and hope that their research has some impact in the scientists' community and society in general. For many years, citation counts have been used for this goal. This research evaluation approach has produced interesting results identifying the complex nature of Physics impact in the research community (for instance see refs. [6], [15], [9]). This identification of diverse science research impacts is important to research managers/ sponsors/ evaluators, and of course performers. They are interested in the types of people and organizations citing the research outputs, and whether the citing audience is the target audience. Also, they are interested in whether the development categories and technical disciplines impacted by the research outputs are the desired targets. Since fundamental research can evolve along myriad paths, tracking diverse impacts becomes very complex.

Recently, scientists have addressed the problem of c-

itation in scientific research from different perspectives: looking for topological description of citation [2], or for power laws in citation networks [13], or obtaining power laws in number of cites received by journals according to their number of published papers [6], or through two-step competition model relating the number of publications and number of cites. These different approaches use power laws trying to obtain simple results from complex interactions, assuming that the precise details of the interactions between the parts of the system play no role in determining the overall behavior of the system [14]. Other approaches try to find some kind of universality in the behavior of research institutions [1],[12]. However, in order to obtain a detailed representation of the system it is important to know the details of the interactions. In such case, the creation of roadmaps for science and technology and with these roadmaps to analyze the retrospective of the research and to define possible perspectives [7], [5] is an interesting and useful approach to describe and to use the impact of scientific research. Also in this sense the analysis of the cites and authorship from a social network perspective gives other useful information to characterize scientific disciplines [10], [11]. However, these approaches: scaling, networks and roadmaps between others, have limitations due to the fact that they explore partially the available data on the citation system. The detailed analysis of all the available data of the citing profile is required to obtain more information and knowledge. Up to now there is no such kind of methodology to deal with the information available through cites of the scientific article. To overcome the above mentioned limitations

of these techniques, we present a phenomenological approach to deal with the information available and obtain a more detailed description of this complex system. The aim of this paper is to show how we can obtain a profile of cited articles through the analysis of the citing papers and get a more complete representation of the impact of science. The application of this kind of phenomenological detailed description is useful to obtain a different and illustrative view of the complex systems.

The enhanced coverage of the research literature by the Web version of the Science Citation Index (SCI-~5300 leading research journals) allows a broad variety of bibliometric analyses of R&D units (papers, researchers, journals, institutions, countries, technical areas) to be performed.

Aggregation of citation number counts is characteristic of almost all published citation studies[6],[13], [1]; this approach identifies R&D units that have had (and have not had) impact on the user community. However, as we have already mentioned, this kind of analysis represents a limited perspective, therefore we require an approach that utilizes all the available citing data and could help answer questions such as:

What types of people and organizations are citing the research outputs; is this the desired target audience?

What development categories are citing the research outputs?

What technical disciplines are citing the research outputs?

What are the relationships between the citing technical disciplines and the cited technical disciplines?

The aim of the present study is to show the power and capability of this new phenomenological approach to citer profiling. It is necessary to stress that the aim is not to assess the productivity and magnitude of impact of any individual researcher, research group, laboratory, institution, or country. To perform such an assessment, the authors would need a charter and statistically representative data based on the unit of assessment, i.e. to make a portrait of the research impact according with the current available scientific databases.

The organization of this paper is the following: In the second section, we summarize the methodology, and describe citation mining. In the third section, we present the results of analyzing four sets of papers. In the following we will refer to these papers as cited papers, in order to distinguish them from the citing papers that are the papers in which the cited papers are referenced. We profile the four selected paper sets through the analysis of the characteristics of the citing authors, journals where the citing papers appeared, references in the citing papers, and also through the analysis of linguistic correlations in the abstract of the cited and citing papers as well as the titles and the keywords, and other registers available in the SCI database. Finally, we conclude with some remarks on the present study.

2 METHOD

In this section we describe a simple procedure to incorporate much of the SCI information in the analysis of the impact of scientific papers. First, we identify the

types of data contained in the SCI (circa early 2000), and the types of analyses that will be performed on this information (see Table 1).

Table 1 shows a record from the SCI, without the field tags. The actual paper that it represents is referred in the following description as the 'full paper'. Starting from the top, the individual fields are:

Table 1	SCI RECORD
Title	the complete title of the actual paper
Authors	all the authors of the actual paper
Source	journal name (Nature)
Issue/ Page(s)/ Publication Date	
Document Type	Article, notes, review, letters
Cited References	the number and names of the references cited in the full paper.
Times Cited	the number and names of the papers (whose records are contained in the SCI) that cited the full paper. Thus, the number provided by this field is a lower bound.
Related Records	
Abstract	the complete Abstract from the full paper
Keywords Plus	keywords supplied by the indexer. In this example, no Keywords were supplied by the author, but the SCI contains a field for author Keywords, if supplied.
Addresses	organizational and street addresses of the authors. For multiple authors, this can be a difficult field to interpret accurately. Different authors from the same organizational unit may describe their organizational level differently. Different authors may abbreviate the same organizational unit differently.
Publisher	

Before proceeding further, we define the overall study objectives, followed by the approach chosen. The purpose is to identify the infrastructure and technical characteristics of the citing community, by stratified categories. The approach is to perform bibliometric analysis of the citing papers to identify the infrastructure, text mining (extraction of useful information from text using computational linguistics mainly) of the citing papers to identify the main technical themes and their relationships, and then integrate the bibliometrics and text mining results to obtain a unified picture of the citing community.

Specifically, we want to present a summary analysis of the citing paper information. This establishes boundaries on the population to be cited, the fields of the cited records to be analyzed, and the statistical requirements for the citing population. The population to be cited could be (and is) an individual paper, the papers from a single author, the papers from an organizational unit, the papers from a technical discipline, the papers from a country, and/ or various combinations of the above. The key fields of the citing records will be analyzed.

Title record is used in text mining together with the other unstructured text fields, Abstracts and Keywords, to perform the correlation analysis of the themes in the cited paper to those of the citing papers. Computational linguistics analysis is then performed.

Author records used to obtain multi-author distribution profiles could be computed (e.g., number of papers

with one author, number with two authors, etc.).

Counts in Source field can lead to journal name distributions, theme distributions, and development level distributions.

Document Type register allows distributions of different document types to be computed (e.g., three articles, four conference proceedings, etc.)

Language field allows distributions over languages to be computed.

Cited References allows a historical analysis of the problem to be performed, and this field can be used to analyze the interrelations between different groups working on related problems.

Times Cited register would be important if the citing papers are of sufficient vintage. Then their multiplier effect would be of interest, and could be computed. The distribution profile of times cited of the citing paper would be generated.

The Addresses register allows distributions of names and types of institutions, and countries, to be generated. Institution and country combinations would be of special interest, and could be correlated with author combination distributions.

The present demonstration of citation mining includes a comparison of a cited research unit from a developing country with a cited research unit from a developed country. It also compares a cited unit from a basic research field with a cited unit from an applied research field. Specifically, the technique is being demonstrated using selected papers from a Mexican semiconductor applied

research group (MexA), a United States semiconductor applied research group (USA), a British fundamental research group (BriF), and a United States fundamental research group (USF) (see Table 2). These papers were selected based on the authors' familiarity with the topical matter, and the desire to examine papers that are reasonably cited. Here, we select these analyzed sets considering at least 50 external cites in order to have a good phenomenological description.

Table 2		Cited Papers Used for Study
Group	Times Cited	PAPERS
MexA	59	Nair, 1988 Sem. Sc. Tech. 3 , 134 Nair, 1989 J Phys D - Appl Phys 22, 829 Nair, 1989 Sem. Sc. and Tech. 4, 191 Nair, 1994 J Appl Phys, 75 , 1557
USA	88	Tuttle, 1995, Prog. Photovoltaic 3, 235 Gabor, 1994, Appl. Phys. Lett. 65, 198 Tuttle, 1995, J. Appl. Phys. 78, 269 Tuttle, 1995, J. Appl. Phys. 77, 153 Nelson, 1993, J. Appl. Phys. 74, 5757
BriF	119	Mehta, 1989, Physica A, 157, 1091 Mehta, 1991, Phys Rev Lett, 67, 394 Barker, 1992, Phys Rev A, 45, 3435 Mehta, 1996, Phys Rev E, 53, 92
USF	307	Jaeger, 1992, Science, 255, 1523

In addition, selection and banding of variables are key aspects of the bibliometric study. While specific variable values are of interest in some cases (e.g., names of

specific citing institutions), there tends to be substantial value in meta-level groupings (e.g., institution class, such as government, industry, academia). Objectives of the study are to demonstrate important variables, types of meta-level groupings providing the most information and insight, and those conditions under which non-dimensionalization become useful. However, we present also two analyses at the micro-level involving specific correlations between both citing author and references for BriF and USF papers. This latter analysis is directly important for the performers of scientific research. In addition, text mining could be performed on the text fields (mainly the Abstract, but including the Title and Keywords) to supplement the analysis on the semi-structured and structured fields.

3 RESULTS

This section presents the bibliometric and text mining results, showing the advantages and broad perspectives offered by these techniques, both alone and combined. The results are presented in graph and tabular forms. In order to organize the presentation we divide our results in bibliometrics and textmining analysis.

3.1 Bibliometrics Analysis

Figure 1 contains a bar graph of multi-author distribution for the four sets analyzed. The ordinate represents the fraction of total papers published in each author band, and the abscissa represents the number of authors

per paper. The most striking feature of this graph is the behavior at the wings. The papers citing basic research dominate the low end (single author), while the papers citing applied research dominate the high end (6-7 authors). The papers citing basic research (BriF and USF) have a similar number of authors per paper, with a maximum in the frequency distribution at two authors per paper. The USA citing papers show gaussian-like authorship distribution with three and four authors per paper, while the MexA group citing papers show a distribution similar to the groups citing fundamental research papers but with fewer single-author papers. These four sets show author distributions where 90% of the papers had less than six authors. These results confirm the diversity of collaborative group compositions over different disciplines and levels of development.

Generally, as projects become more applied, they tend to become larger and more expensive, and require more resources. They also usually require the integration of multiple disciplines. Both these characteristics typically result in larger research groups, and hence in more contributors to a project and its resulting documents. Experimental work usually involves larger teams than theoretical work, while modeling and simulation activities tend to allow more individual efforts. The strong experimental emphasis of the two applied semiconductor groups, with little evidence of computer simulation shown, results in large teams on average. The more balanced theory/ experiment combination of the basic research group tends to suppress larger team efforts in favor of more individualized research. In addition, the in-

trinsic nature of sandpile vibration research, as opposed to elementary particle or fusion research, does not require large facilities and large research teams.

The citing journal discipline frequency is shown in Table 3. Clearly, each paper set has defined its main discipline well. Also, there is a symmetry in the cross citing disciplines. USF and BriF groups were cited around 80% in fundamental journals and close to 10% in applied journals. Similarly, MexA and USA groups were cited close to 50% in applied journals and 45% in fundamental journals. These journal discipline results suggest that the applications developed by the MexA group have a strong impact on chemical journals, while the applications developed by the USA group strongly impact physics journals. A point to be stressed is that only the fundamental papers received cites in journals clearly outside of their disciplines.

Table 3		Citing	Journal	Theme
<i>Theme</i>	<i>MexA</i>	<i>USA</i>	<i>BriF</i>	<i>USF</i>
Phys.	20%	44%	83%	79%
Bio.	0	0	0	1%
Chem.	25%	1%	2%	2%
Enviromental	0	0	1%	0
Mate. & Eng.	54%	55%	12%	13%
Multidiscipl.	0	0	2%	5%

The discipline distribution of the citing papers, produced by analyzing the papers' Abstracts and Titles, is shown in Table 4. It is slightly different from Table 3. As concluded in the text mining, these free-text fields provide far more precise information than can be obtained

from the journal discipline. Multi-disciplinary journals can publish uni-disciplinary papers from many different disciplines. Also, the journal categories, determined by ISI, are not a unique reflection of specific contents (e.g., an environmental journal can accept engineering papers, a materials journal can accept physics papers, etc.). However, the chemical nature of the papers/ journals impacted by the MexA group is confirmed.

Table 4		Citing	Article	Theme
<i>Theme</i>	<i>MexA</i>	<i>USA</i>	<i>BriF</i>	<i>USF</i>
Phys.	10%	22%	86%	83%
Bio.	0	0	0	1%
Chem.	26%	5%	0%	1%
Mate. & Eng.	64%	73%	12%	14%
Multidiscipl.	0	0	2%	1%

In three of the four sets analyzed, the component papers were published in different years (see Figure. 2). The MexA set was published from 1989 to 1994, USA from 1994 to 1995, BriF from 1989 to 1996, while USF includes only one paper published in 1992. Figure 2 shows a clear oscillating behavior of USA and BriF, due partly to the different dates of paper publication. Also, most of the sets have between 10% and 20% of cites per year, while the USA set received 38% of the cites in 1998.

The single highly-cited paper feature of the USF set allows additional analyses and perspectives. In Figure 3, the USF citing paper disciplines are shown as a function of time. As time evolves, citing papers from disciplines other than those of the cited paper emerge. An important point is the four-year delay of the systematic

appearance of engineering and materials science citing papers.

Table 5 shows that most cites appear in articles. The four analyzed sets are cited in review articles and letters. This indicates the relevance of the analyzed papers. One important point is that only the fundamental papers are cited in notes, and only the USF paper was cited in an editorial document.

Table 5		Citing	Paper	Type
<i>Paper type</i>	<i>MexA</i>	<i>USA</i>	<i>BriF</i>	<i>USF</i>
Article	95%	96%	92%	89%
Letter	3%	1%	2%	2%
Review	2%	3%	2%	5%
Note	0	0	4%	3%
Edit.Mat.	0	0	0	1%

Table 6 shows that English is the dominant language of all the paper sets analyzed. However, the surprising appearance of a significant number of citing papers written in Romanian for the MexA set indicates that MexA's work is important for at least one developing country.

Table 6		Citing	Paper	Language
<i>Language</i>	<i>MexA</i>	<i>USA</i>	<i>BriF</i>	<i>USF</i>
English	93%	100%	99%	99.7%
Romanian	7%	0	0	0
French	0	0	1%	0
German	0	0	0	0.3%

Figure 4 shows the profile of the citing institutions. Clearly, academia has the highest citing rates. Industry follows closely the advance of high-technological developments, but is not following directly the advances in

fundamental research. Research Centers follow applied and fundamental research about equally. Direct government participation is not significant in the fields studied. Government/ national laboratories were classified under research centers.

There are 44 countries represented in the citing paper sets analyzed. Figure 5 shows only those countries with at least 10% of the citing countries for a set. USA has the most cites in aggregate. India has the largest cites of the MexA set; Japan has the largest cites of the USA set. This fact is due to the different nature of the applied technology developed by MexA and USA. The USA set contains work related to high technology, and the MexA set is dedicated to explore low-cost technology. Therefore, this last set is cited by the less affluent countries of India, Romania and Mexico. India and Mexico also cite fundamental research, but not Romania. It is important to stress that if no low-cost technology papers were considered, these latter countries would not appear in this graph, and only developed countries would appear. Another point is that England does not cite USA works.

Figure 6 shows clearly that the low-cost technology papers are cited by developing countries. Developed countries cite the mostly high-technology papers, there exist a clear asymmetry in the interests and of course the number of cites from developing countries is lesser than cites from developed ones..

The analysis of the most common citing authors is presented in Figures 7 where the frequency of an author citing USF (triangle) or BriF (square) is plotted. Figure

7 shows that there is a closed relation between the citing authors for both BriF and USF groups, actually there is a common citing author who occupied the highest position in the frequency plot in both sets (Hermann, HJ). Three of the highest citing authors are not shared between the citing sets of USF and BriF. Jaeger and Nagel are the authors of the USF paper and Mehta is one of the authors of BriF paper. They maintain awareness of each other's work. In contradistinction, Figure 8 shows that MexA and USA have no intersection between their topics (low cost photovoltaic thin films and high efficient photovoltaic cells, respectively), from the perspective of the highest citing authors. Previous citation results have shown that applied research authors tend to cite more fundamental research, along relatively stratified lines. In Figure 8, it is clear that the maximum citing author of the MexA group is a Romanian researcher.

In Figure 9, it is clear that there are common features in the number of references in those papers that cite the core applied and fundamental papers, but there are also some differences. For instance, at the lower end of the spectrum (0-20), the applied papers' citing papers dominate. At the higher end of the spectrum (21-50+), the fundamental papers' citing papers dominate, with the exception of the BriF anomaly at 41-50.

There are many possible reasons for these differences, and separating out the effects is complex. There are two different technical disciplines, and each one has its citing culture and traditions. Also, each technical discipline has a different level of research activity, and this could influence the magnitude of citations generated. Basic re-

searchers tend to document more, and therefore produce a larger literature to cite. Finally, there may be different citing practices in basic and applied research.

Frequency analysis of the most common references in the citing papers provides insight to co-cited papers, and allows a historical perspective to be obtained. The reference-frequency for the USF and BriF citing papers is shown in Figure 10. Here we see that the fundamental papers dealing with sand-piles are actually correlated, because their highest occurrent references in their citing papers are common references (each line has two symbols).

In Figure 10 also we observed that Faraday's work (1831) appears within the twenty papers most cited in the USF and BriF citing papers. This indicates the fundamental and seminal character of the experimental work performed by Faraday. Also, Reynolds' work (1885) appears within the twenty most cited papers in the references of the BriF set. These two references also indicate the longevity of the unsolved problems tackled by the USF and BriF groups. The highest frequency co-cited papers have three interesting characteristics. They are essentially all in the same general physics area, they are all published in fundamental science journals (mainly physics), and they are all relatively recent, indicating a dynamic research area with high turnover.

The corresponding analysis of the most common references in the applied MexA and USA groups is presented in Figure 11. Here clearly is seen that these two groups has no correlations, because they have no common references between their highest occurrent references in their citing papers are common references. However, in the

detailed analysis of the correlation there is one paper in the intersection of these two groups.

This ends the bibliometric analysis. The following section illustrates the usefulness of text mining analysis.

3.2 Text mining

The purpose of the text mining is to perform trans-citation linguistic pattern analyses, and make trans-citation comparisons. Two text mining techniques will be used for the following analyses. Phrase frequency analysis will be used to identify the main technical themes of the citing papers relative to the cited papers. Phrase proximity analysis, mainly phrase clustering and taxonomy generation, will be used to show the relationships among themes and category structures of the overall technical citing disciplines. The findings for each of the four paper groups are summarized. Phrase frequency results are presented for the first three groups, and, in addition, phrase clustering results are presented for the fourth group.

3.2.1 USA

The highest frequency single, adjacent double, and adjacent triple word phrases from its USA citing papers aligned with the themes of the cited paper can be seen in del Rio et al. [4].

The central themes and specific phrases used in the cited paper are replicated in the citing papers. There were no phrases in the citing papers that represented themes or disciplines significantly different from those in the cited paper, above a frequency of unity. While

there could possibly be phrases representative of different themes with a unity frequency, some minimal theme coherence was desired. The citing readership appears to be strongly concentrated in the thematic areas of the cited paper. One suspects that the audience obtained is the target audience for this paper, at least in terms of thematic interest. We could not find phrases reflecting themes other than cited paper.

3.2.2 MexA

The central themes and specific phrases used in the cited paper are replicated in the citing papers. There were two phrases in the citing papers that represented themes or disciplines other than those in the cited paper, above a frequency of unity (See Table 7). These additional themes reflected use of the solar coatings for automobile windows, in addition to the core architectural (building) applications. This is a very small extrapolation. Again, the citing readership appears to be strongly concentrated in the thematic areas of the cited paper.

Table 7	Phrases Reflecting Themes other than Cited Paper (Me
Frequency	Theme
2	AUTOMOBILE
2	ARCHITECTURAL AND AUTOMOBILE

3.2.3 BriF

Use of text mining capabilities, such as computational linguistics, allows only those applications and extra-

discipline papers of interest to be identified, and the requisite information can then be obtained from reading the Abstracts. In addition, the computational linguistics provides a structure and categorization of these myriad applications, allowing the larger context of application themes to be displayed and understood. While phrase frequency algorithms were used for the present study, and proved adequate, specifically-tailored co-occurrence and clustering algorithms are being developed to improve the efficiency of the application papers identification and retrieval process, see Table 8.

Table 8	Phrases Reflecting Themes other than Cited Paper (Bri
Frequency	Theme
5	CAR*
4	ALLOY
4	TRAFFIC
4	WATER PROTON
3	MexAGNETIC
3	PROTON TRANSVERSE
3	TRAFFIC FLOW
2	AQUIFER
2	EXPRESSWAY
2	FOOD
2	FOODSTUSFFS
2	ICE
2	NUCLEAR
2	TUNGSTEN
2	WATER PROTON TRANSVERSE

3.2.4 USF

The citing papers to USF paper representing different categories of development and different disciplines from those of the cited paper are portrayed graphically in Figure 12, the axes are Category, Alignment and Papers. The category represents the level of development characterized by the citing paper (1=basic research; 2=applied research; 3=advanced development/ applications), and the second number represents the degree of alignment between the main themes of the citing and cited papers (1=strong alignment; 2=partial alignment; 3=little alignment). There are three interesting features on Figure 12. First, the tail of total annual citation counts is very long, and shows little sign of abating, this is one characteristic feature of a seminal paper. Second, the fraction of extra-discipline basic research citing papers to total citing papers ranges from about 20-40% annually, with no latency period evident. This instant extra-disciplinary diffusion may have been due to the combination of intrinsic broad-based applicability of the subject matter and publication of the paper in a high-circulation science journal with very broad-based readership. Third, there was a four-year latency period before the higher development category citing papers began to emerge, one can see that black dots, earlier cites, are completely in the category. This correlates with the results from the bibliometrics component. The latency could have been due to the information remaining in the basic research journals, and not reaching the applications community, or the time that an application needs to be develop-

d is of the order of four years. Thus, the basic science publication feature that may have contributed heavily to extra-discipline citations may also have limited higher development category citations for the latency period.

The present phenomenological approach of identifying impact themes through text mining allows a much more detailed and informative picture of the impact of research to be obtained compared to semi-automated journal classification comparison approaches [3]. It represents the difference between stating that a "Physics paper impacted Geology research" and a "paper focused on sand-pile avalanches for surface smoothing impacted analyses of steep hill-slope landslides".

In the final data analysis, a taxonomy of the USF citing papers was generated using phrase clustering. The Abstracts of all the USF citing papers were converted to phrases and their frequencies of occurrence with use of a Natural Language Processor contained in the TechOasis software package were recorded. The 153 highest frequency technical content phrases (expert-selected) were exported to a statistical clustering software package (WIN-STAT), and based on the relations among phrases generated by this package, a taxonomy was generated by the authors. A particularly helpful output for each clustering run was the dendrogram, a tree-like diagram showing the structural branches that define the clusters. Figure 13 is one dendrogram based on the 48 highest frequency phrases (for illustration purposes only). The abscissa contains the phrases that are clustered. The ordinate is a distance metric. The smaller the distance at which phrases, or phrase groups, are clustered, the closer is the

connection between the phrases.

Thus, samples of the phrases combined, at the right hand side end of the graph, are DISSIPATION, COLLISIONS and ENERGY, followed by MIXTURES ALTER-NATING LAYERS SMALL GRAINS LARGE GRAIN-S STRATIFICATION; in the middle part of the graph VIBRATION and AMPLITUDE can be found. At some later time, the VIBRATION-AMPLITUDE combination is grouped with the GRAVITY-GRANULAR MEDIA combination to form the next hierarchical level grouping, and so on.

Many agglomeration techniques were tested; the Average Neighbor method appeared to provide reasonably consistent good results. Analyses were performed of the numerous cluster options that were produced. The following is one of the top-level cluster descriptions that represented the results of the phrase and word lists clustering best, as well as the factor matrix clustering from the TechOasis results (more clusters can be found in Kostoff et al. [8]).

The highest level categorization based on the highest frequency 153 phrases produced three distinct clusters [8]: Structure/ Properties, Flow-Based Experiments, Modeling and Simulation. In the description of the Structure and Properties cluster (right part of the dendogram Figure 13) that follows, phrases that appeared within the clusters will be capitalized.

This cluster contained MIXTURES of LARGE GRAIN-S and SMALL GRAINS, with STRATIFICATION along ALTERNATING LAYERS based on SIZE SEGREGATION and grain SHAPE and GEOMETRICAL PRO-

FILE. The MIXTURE forms a PILE with an ANGLE of REPOSE. When the ANGLE of REPOSE is LARGER than a critical ANGLE, DYNAMICAL PROCESSES produce AVALANCHES, resulting in SURFACE FLOW within THIN LAYERS.

4 CONCLUSIONS

In this paper, we present a phenomenological technique to analyze some aspects of a complex system like the multi-path non-monotonic impact of scientific research. The result of using citation mining (bibliometrics and text mining) to analyze the impact of science, through the use of the available information from the Web of Science ISI, allows the profiling of the citing papers of a given paper, research group, scientific organization, etc. We illustrated citation mining through the analysis of four research groups. This analysis provided multiple facets and perspectives of the myriad impacts of research. Citation mining offers insights that would not emerge if only separate citing paper counts were used independently, as is the prevalent use of citation analysis today. Moreover, by removing the need to actually read thousands of abstracts through the use of text mining, comprehensive assessments of research impact become feasible. One important result from the basic research citation mining [8] was that impacts are possible in myriad fields and applications not envisioned by the researchers. This reference also questioned whether fundamental sand-pile research would receive funding from Tokamak, air traffic control, or materials programs, even though sand-pile research

could impact these or many other types of applications, as shown in the paper. The reference concluded that sponsorship of some unfettered research must be protected, for the strategic long-term benefits on global technology and applications!

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Figure Captions

Figure 1. Multi-author distribution for the four paper sets analyzed .

Figure 2. Time profile of citing papers.

Figure 3. Time profile of citing papers for USF. Here it is important to stress a four year dealy in the appearance of applied citing papers.

Figure 4. Institution profile of citing papers. Most of the related research to this two fields is perfomed in academic institutions.

Figure 5. Country profile of citing papers. The main objective in the MexA research is to obtain a low cost technology, this marks the countries interested in this kind of work.

Figure 6. Citing country development phase. In the fundamental topic it is clear the difference between the number of paper produced in developed and developing countries. However, again the topic of low cost technology is more interesting for developing countries (lines are drawn in order to guide eyes).

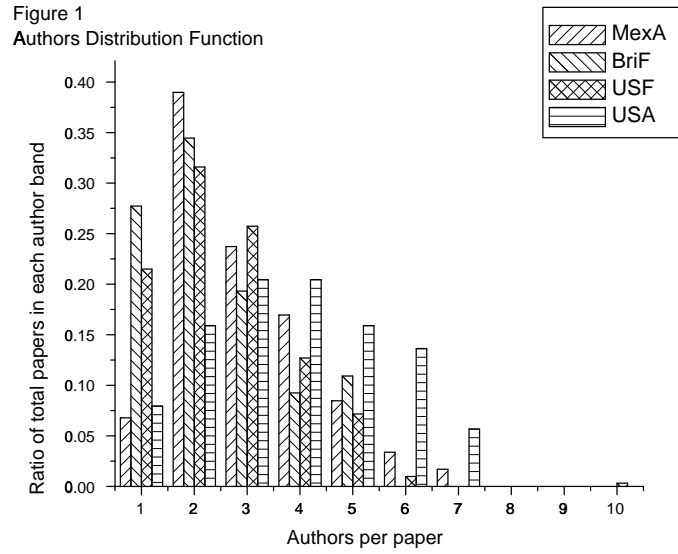
Figure 7. Correlation between the citing authors in fundamental sets. One line with two symbols (triangle and square) means close relation.

Figure 8. Correlation between the citing authors in applied groups. Here there is no close relation.

Figure 9. Citing paper reference distribution.

Figure 10. Reference-frequency for fundamental sets. One line with two symbols (triangle and circle) means that this reference appears in both (BriF and USF) sets.

Figure 11. Reference-frequency for applied sets. There is no close relation, because there is no line with two



symbols.

Figure 12. Category and alignment in the citing papers of USF. Black symbols represent to earlies cites, while empty symbols indicate recent cites.

Figure 13. Dendrogram: tree-like diagram defining clusters of realted words in the citing papers of USF. Lesser distance means close relations within phrases.

Figure 2
Time Profile of Citing Papers

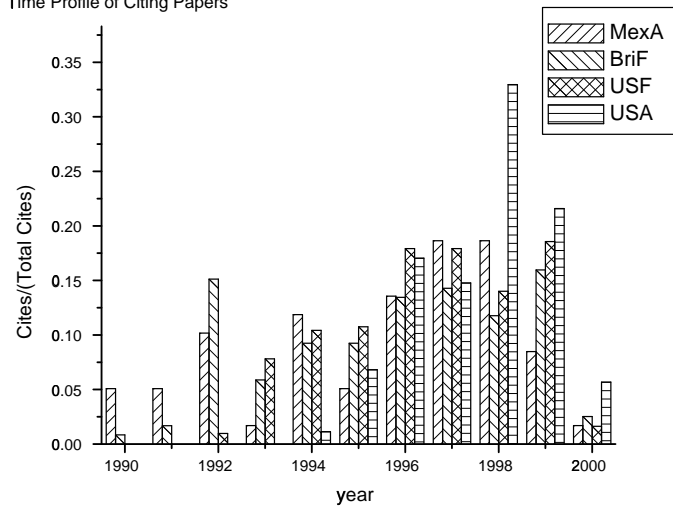


Figure 3
Time Profile of Citing Papers

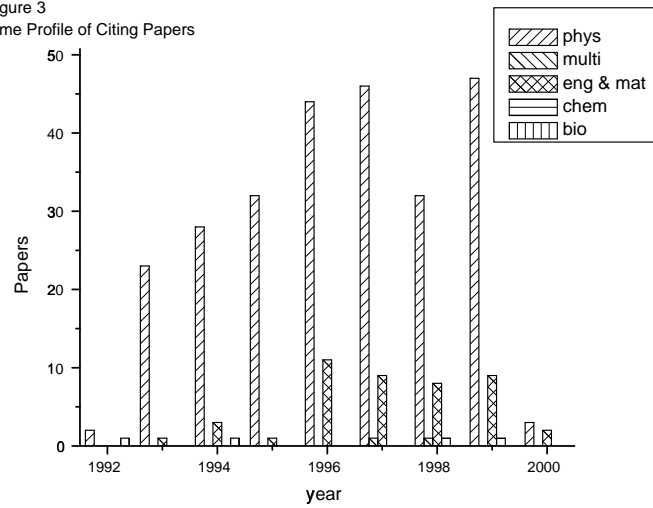


Figure 4
Citing Paper Institution Profile

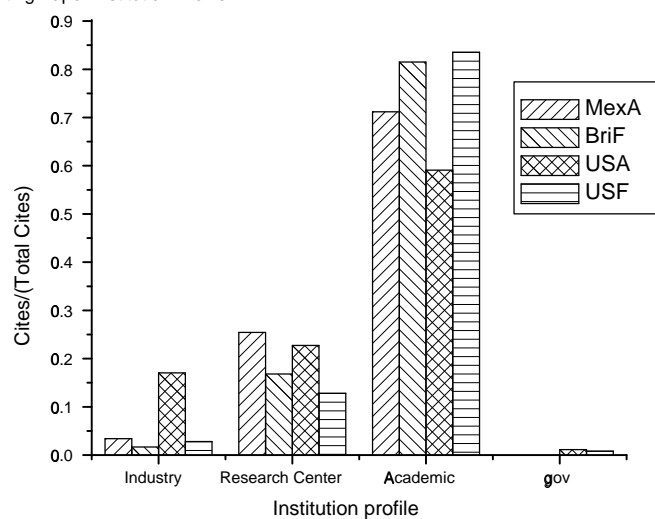


Figure 5
Citing Paper Country Profile

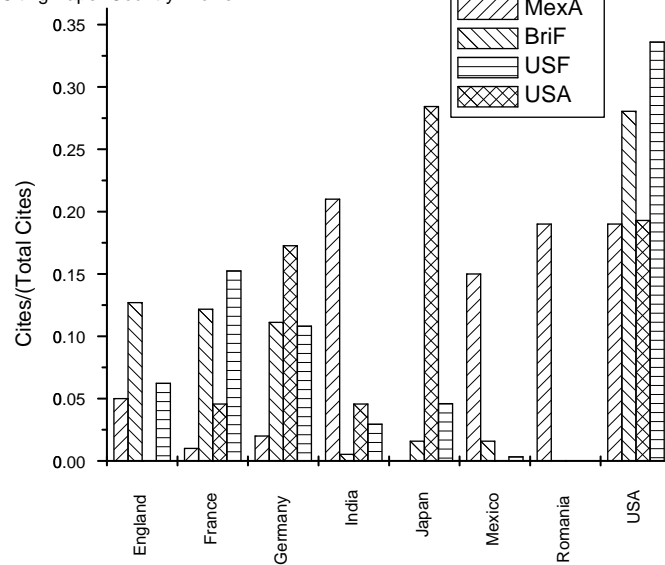


Figure 6

Citing country development phase

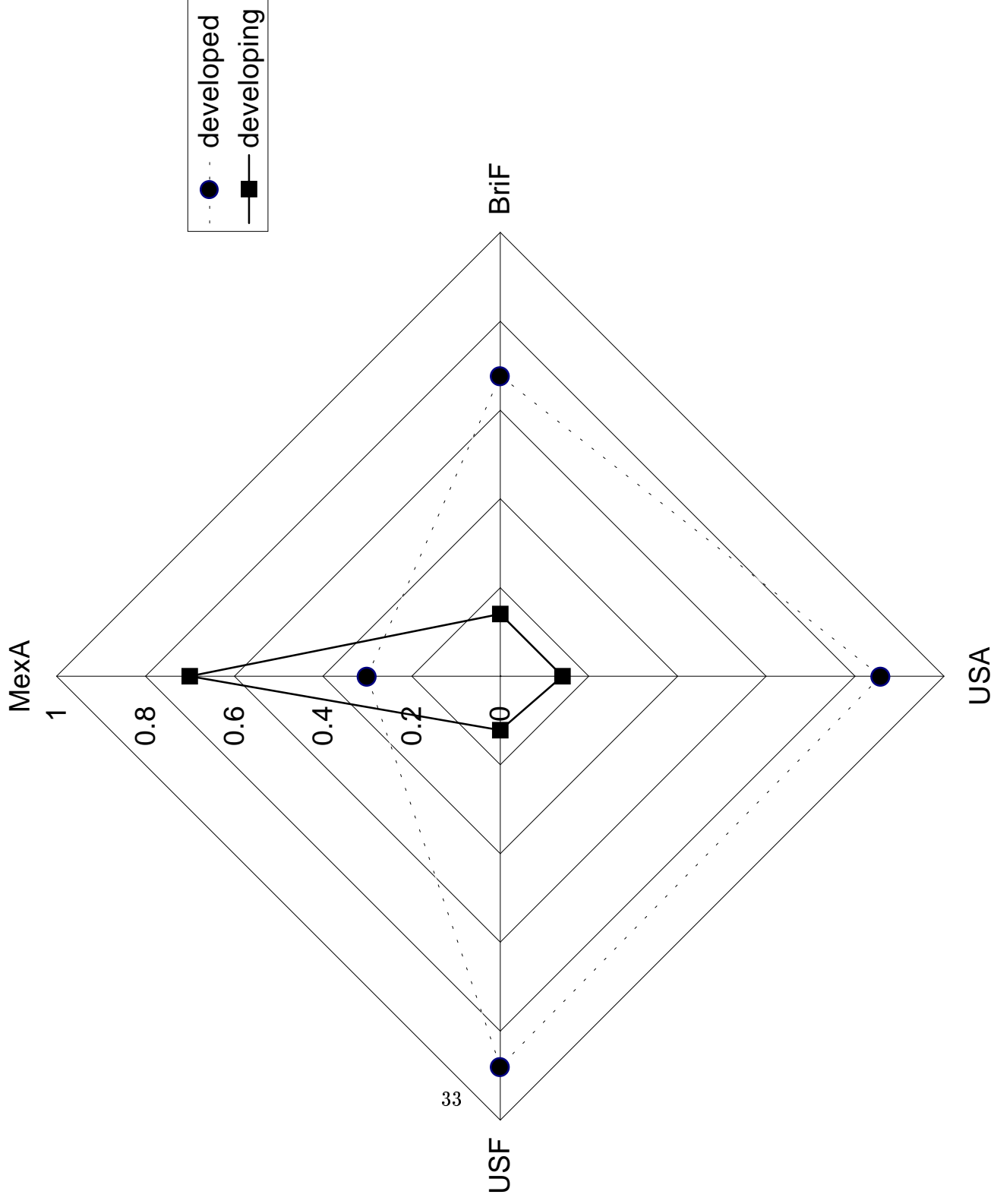


Figure 8

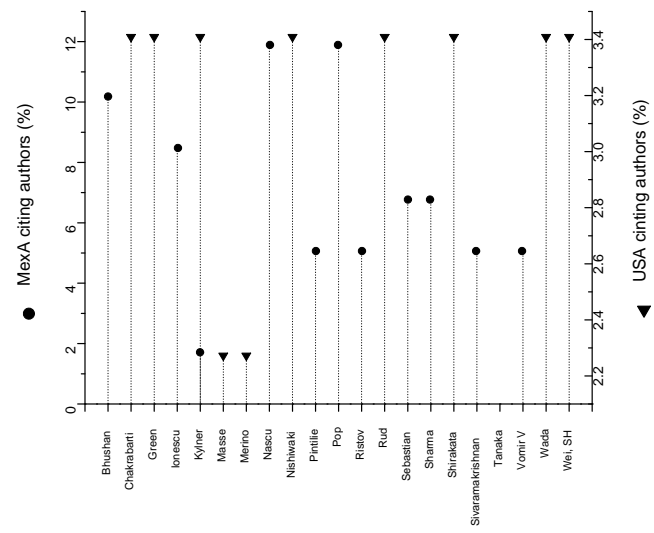


Figure 7

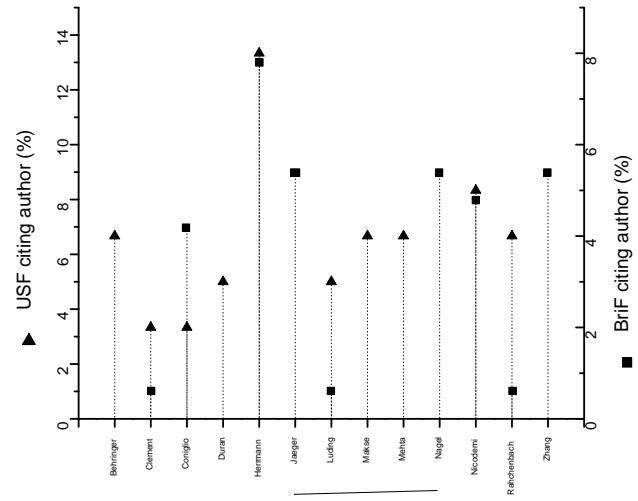


Figure 9
Citing Paper References Distribution

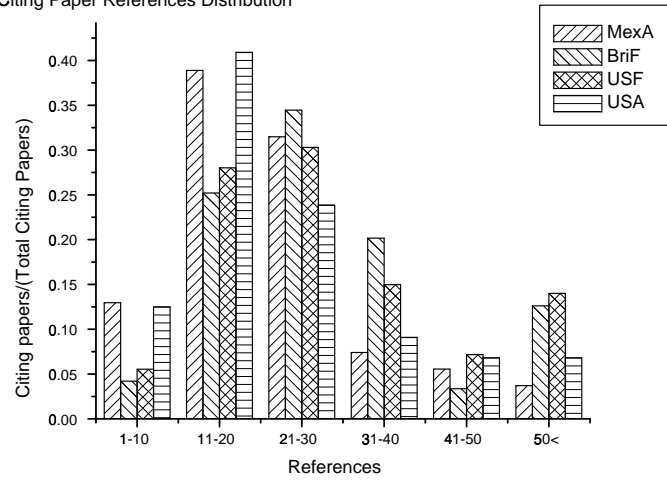
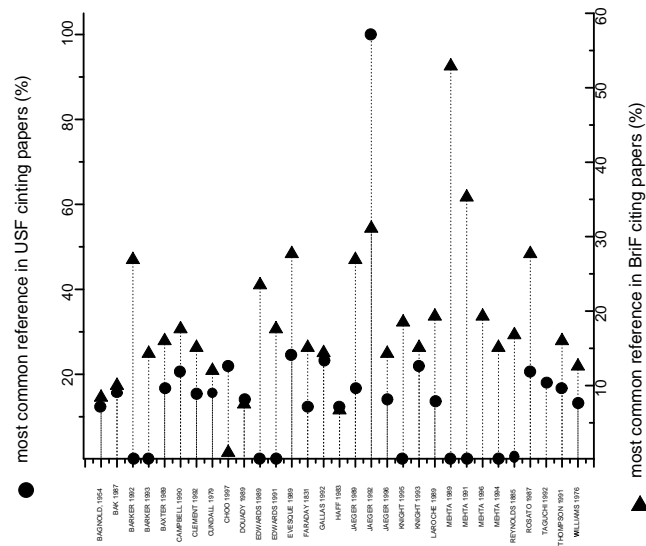


Figure 10



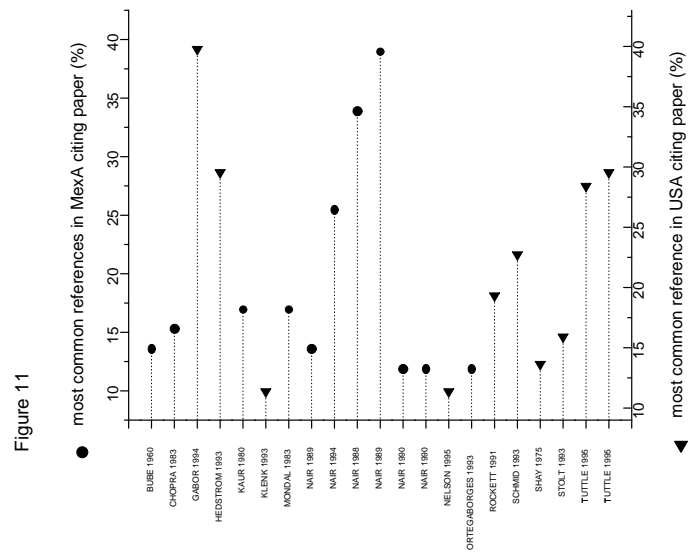
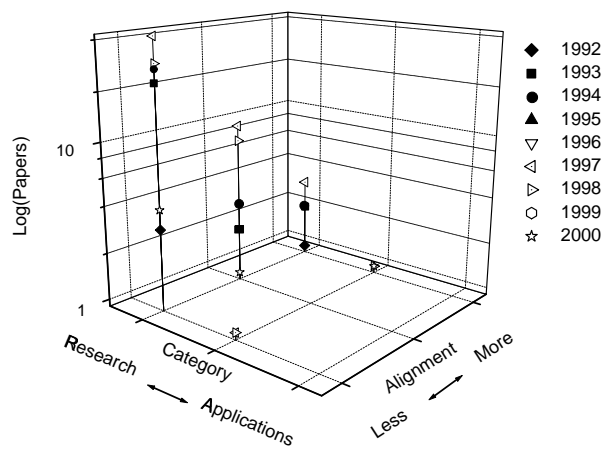


Figure 12



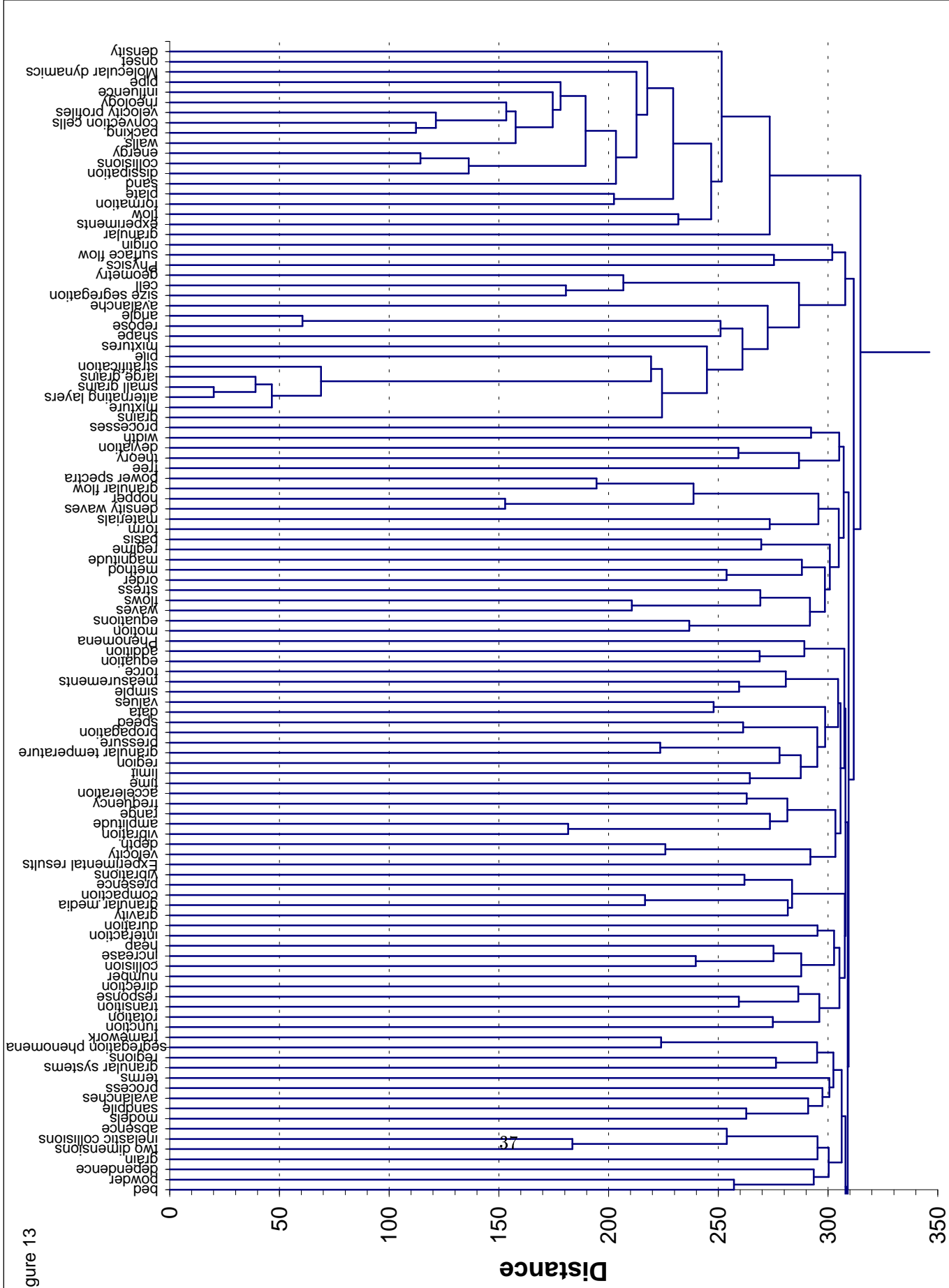


Figure 13